

MAG-Laser Hybrid Welding that Increases Amount of Axial Collapse Energy Absorption in Collisions

Shigeru KOBAYASHI* Tetsuya GOMI*

ABSTRACT

A technology for the application of MAG-laser hybrid welding that enhances the axial collapse column energy absorption during a collision was developed. Taking advantage of the gap weldability that is a characteristic of MAG welding and of the penetrability characteristic of laser welding, this MAG-laser hybrid welding technology resolved issues that conventional laser welding could not readily address, such as lap welding Zn-coated materials together, and welding areas where there are gaps.

The axial collapse column energy absorption during collisions obtained in drop weight tests using hat-shaped specimens on which this MAG laser hybrid welding technology had been applied was approximately 40% greater than that absorption when spot welding had been applied.

1. Introduction

Demands continue to increase for greater fuel economy with a view toward global environmental protection as well as the demands for reduction in chassis weight and for enhanced collision safety and related matters. It is known that the use of laser welding and other such continuous welding instead of conventional spot welding, for members that absorb energy during a collision (such as the front side frames) can enhance energy absorption during collapse. According to Furusako⁽¹⁾ and others, the application of continuous welding employing lasers has been reported to increase energy absorption by about 15% relative to the spot welding. However, the source does not discuss the verification of optimal locations for laser welding nor measures to counter the joint strength decrease, which becomes an issue when welding gaps and when lap welding Zn-coated materials. The application of laser welding will require the resolution of multiple such issues that are unique to laser welding and that have been the main factors impeding its wider adoption.

At present, members that absorb energy during collisions (such as the front side frames) include multiple stamped parts that employ spot welds and other such point welding. To help protect vehicle occupants from the impact of collisions, the function of absorbing impact energy is demanded of these frame parts. With point

welding, however, there are intervals between the joints so that openings form during collapse, and this loss reduces the amount of energy that can be absorbed. Thicker sheets could be used for such materials, or higher strength steel could be used as a countermeasure, but such countermeasures result in increased weight and greater costs. Therefore, MAG-laser hybrid welding that effectively uses the respective strengths of both MAG welding and laser welding was developed together with the technology for its application, which enabled continuous welding that is capable of creating joints in parts of collision members where there are gaps as well as creating joints that experience little loss of joint strength even when lap welding Zn-coated steel. The development also increased the energy absorption during collapse to a higher level than conventional spot welding. This article will give an overview of an application technology for this MAG-laser hybrid welding and report on the results of drop weight tests conducted on hat-shaped specimens using this joining technology.

2. MAG-laser Hybrid Welding Technology

2.1. Issues in Laser Welding

As a countermeasure to the increase in weight that accompanies greater sheet thickness and the increases in material costs and processing costs due to the use of high

* Automobile R&D Center

strength steel, the use of laser welding or other such continuous welding instead of conventional spot welding as a method to join hat-shaped members and increase their collapse energy absorption was studied. In order to apply laser welding instead of conventional spot welding as the method for joining current side frame members, however, it was necessary to resolve issues such as the following that are unique to laser welding.

- (1) The side frames are members used in a rust environment, and therefore they are ordinarily made corrosion-resistant through the use of Zn-coated steel. When laser welding the areas of lapped sheets, portions of vaporized Zn coating remain on the joint and form blow holes^{(2), (3)} (below, “vapor defect”).
- (2) Laser welding forms a joint with molten metal produced by melting the parent metal. In gap welding (where there is a space between the sheets), the bondability is diminished. Even a slight gap (0.2 mm or more) can result in an inability to maintain joint strength^{(4), (5)}.

In addition, even when conventional spot welding is replaced by laser welding of the same part, energy absorption by axial collapse only increases by about 15%⁽¹⁾.

2.2. The Mechanism of Vapor Defects

Figure 1 shows the condition of two lapping sheets of Zn-coated steel that were subjected to laser welding and resulted in defects. When laser welding two tightly overlapping sheets of Zn-coated steel, the heat of the laser can cause the Zn coating on the surfaces of the steel sheets to vaporize and form blow holes that remain inside the joint boundary, so that the strength of the joint is reduced. Numerous pits, which are holes formed in the surface of the joint at points where the vaporized Zn coating has been released into the atmosphere, are also visible. Figure 2 shows blow holes identified using X-rays, and Fig. 3 shows pits that have erupted on the surface.

Typical methods used to reduce the occurrence of blow holes include creating a small gap between the two sheets to discharge the vapor from the Zn coating, for example,

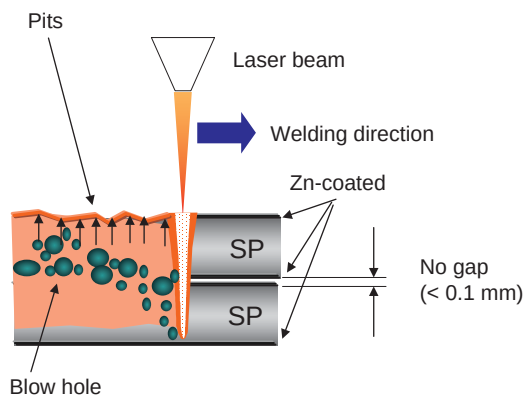


Fig. 1 Schematic defect generation model

by preventing the two sheets from adhering to each other by means of embossing or other such forming applied in advance, and by exposing just the top sheet of the two sheets to a low-intensity laser in advance so that the resulting heat deformation will create minute gaps that allow vapor to be discharged. However, either of these methods involves a front-end process that requires machine processing or other such additional work to be done. Consequently, these cannot be considered simple and certain measures against Zn coating vapor.

2.3. Testing of Zn Coating Vapor Defect Prevention

Attention was therefore focused on joints made at the root of a flange (at the termination of the curve), that can efficiently discharge Zn coating vapor to the outside using gaps and can be expected to provide increased energy absorption during axial collapse. In order to form joints in which defects due to the gap do not occur, MAG-laser hybrid welding technology^{(6), (7)} that combines MAG and a YAG laser was used to make welds on hat-shaped test pieces, and the effects were verified. Figure 4 shows the configuration of equipment used for this testing, and Table 1 shows the welding conditions. The configuration

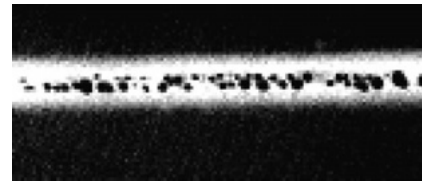


Fig. 2 X-ray inspection of blow hole

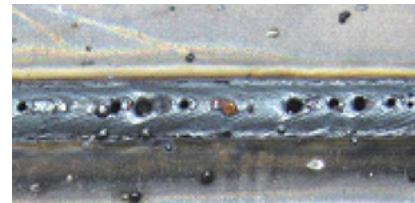


Fig. 3 Surface appearance of pit

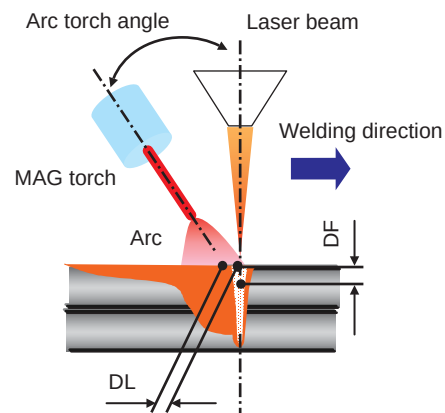


Fig. 4 MAG-Laser hybrid welding configuration

Table 1 MAG-Laser hybrid welding conditions

YAG-Laser power	3.5—4.0 kW
Focus radius	Φ0.6 mm
Defocus distance (DF)	—2 mm
Travelling speed	250 cm/min
Arc current (MODE)	250 A (CMT)
Arc torch angle	25°
Shielding gas	Ar+20%CO ₂
Distance of laser and arc (DL)	2.0—3.0 mm

has a laser beam first directed (DF: defocus) to a point 2.0 mm below the surface of the material to be welded that proceeds in advance, with the arc following behind it. The aim point for the arc was set to 2.0 to 3.0 mm behind the laser irradiation position (DL: distance between the laser and the arc). A Cold Metal Transfer* (CMT), a low-heat arc welding power source of the kind that has recently undergone rapid development, was used as the MAG arc power source.

(*CMT: a low-heat arc welding power source developed by Fronius International GmbH)

2.4. Test Results

Figure 5 shows an overall view of the hat-shaped test piece used in this testing and an expanded view of the area in the vicinity of the termination of the curve indicating the laser aim points. Equation (1) shows the method and the formula for calculating the blow hole incidence per unit length, while Fig. 6 shows X-ray images of each weld made with varying aim points centered on the termination of the curve together with the

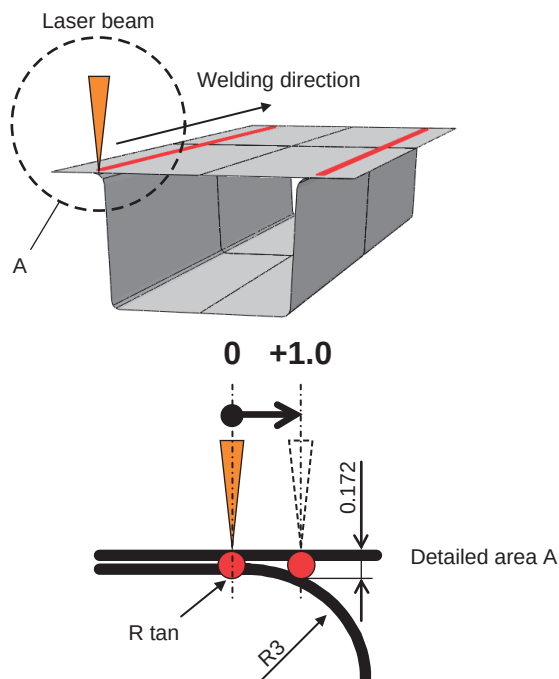
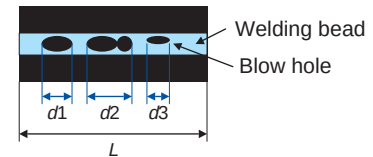


Fig. 5 Verification result of welding position

incidence of blow holes formed there. A blow hole incidence of 30% or more, for which the join strength would be lower than that with spot welding, was taken as a join defect. When the laser aim point moved from the termination of the curve (± 0) toward the side in the direction of the flange (-), the number of blow holes increased suddenly, and the incidence rate already exceeded 30% at a distance of 0.5 mm. When the laser aim point moved from the termination of the curve toward the side in the opposite direction from the flange (+), the gap increased in conformity with the position along the curve so that the number of blow holes decreased suddenly, and the incidence rate became zero at a distance of 1 mm. When the aim point moved 1 mm or more, however, the gap opened up too wide. At a distance of 1.5 mm, a hole was made in the upper sheet due to burn through. The laser aim point positional tolerance on the hat-shaped test piece was, therefore, within the range of 0.0 mm to 1.0 mm from the termination of the curve, which was taken as the origin (Fig. 7). The maximum gap



$$\text{Blow hole incidence} = \frac{\sum d_i}{L} \times 100 (\%) \quad (1)$$

$(i=1,2,\dots,n)$

Welding position (mm)	X-ray inspection of blow hole	Blow hole incidence (%)	Evaluation
-1.5		55.6	Defect
-1.0		60.9	Defect
-0.5		39.7	Defect
± 0		15.4	Good
+0.5		6.3	Good
+1.0		0	Good
+1.5		0 *Burn through	Defect

Fig. 6 Measuring result of blow hole incidence

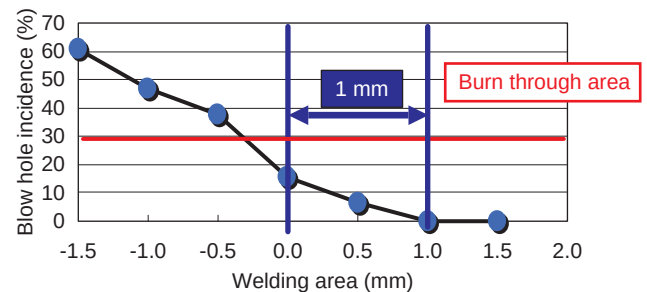


Fig. 7 MAG-Laser hybrid welding joinable area

size was 0.172 mm with the laser aim point of 1.0 mm (+). The above results clarified welding conditions for MAG-laser hybrid welding that do not produce vapor defects and the range for appropriate joins. Figure 8 shows an exterior view of the MAG-laser hybrid welding system used in the present testing.

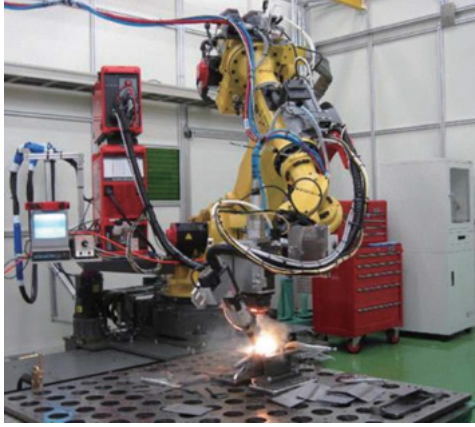


Fig. 8 MAG-Laser hybrid welding equipment

3. Verification of the Effect using Hat-shaped Test Piece

In order to verify the effect from the application of continuous joining by means of MAG-laser hybrid welding, CAE and drop weight testing were used to verify the differences in energy absorption that result from different welding locations and welding methods. The CAE simulation made use of finite element analysis with the general-purpose explicit solver RADIOSS Ver. 4.4.

3.1. Verification by Means of CAE

Figure 9 shows the finite element model for spot welding and for continuous welding as modeled for drop weight tests. The finite element model was 50 mm in height, 70 mm in width, and 300 mm in length with a mesh pitch of 3 mm. The following items (1) to (4) show the welding conditions (welding method and welding location) used for verification:

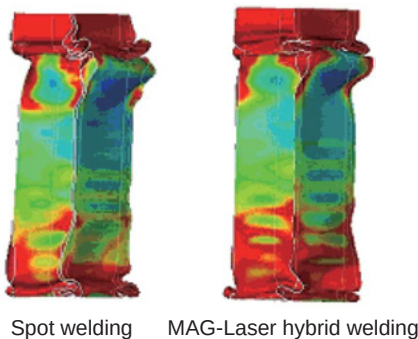


Fig. 9 Axial collapse FEM model

- (1) Spot welding at the flange center (weld interval of 30 mm)
- (2) MAG-laser continuous welding at the flange edge
- (3) MAG-laser continuous welding at the flange center
- (4) MAG-laser continuous welding at the flange root (the termination of the curve)

Using the finite element model described above, the energy absorption when the member collapsed with a stroke of up to 150 mm at a speed of 50 km/h at the time of contact was calculated.

Figure 10 shows results for the comparison of energy absorption with continuous joining at the different welding locations when the energy absorption of spot welding is 100%.

The above results from CAE analysis of hat-shaped test pieces to which the MAG-laser hybrid welding in question had been applied showed that continuous welding applied at the root (the area of termination of the curve) of a hat-shaped vertical wall yielded the greatest energy absorption.

3.2. Verification by Drop Weight Testing

Figure 11 shows the configuration of the hat-shaped

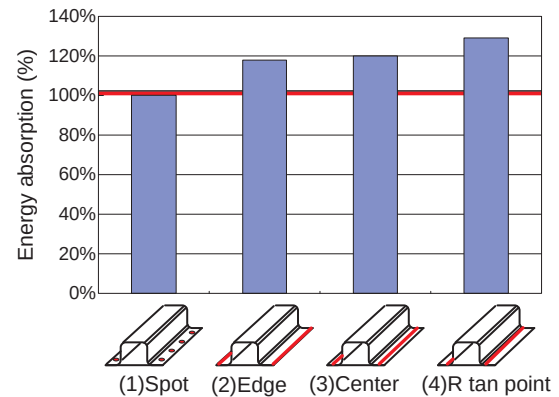


Fig. 10 Comparison of energy absorption between spot welding and MAG-Laser hybrid welding

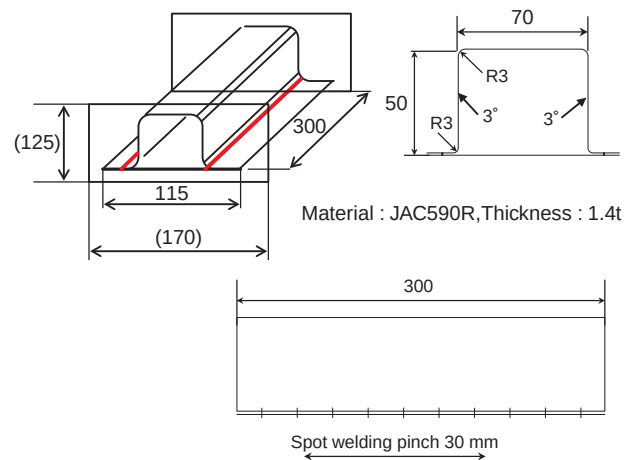


Fig. 11 Configurations of hat-shaped specimen for drop weight tests

Table 2 Drop weight test conditions

Item	Conditions
Drop weight	324 kg
Drop height	9.84 m
Crash speed	50 km/h

test piece used for this testing. The test piece configuration and welding conditions (welding method and welding location) were as in items (1) to (4) describing the finite element model used for verification by CAE. In order to conduct the axial collapse test, end plates with 10 mm thick were attached to each end of the hat-shaped test piece by MIG welding all around the periphery of the plates. The drop weight test conditions including the indenter weight and drop height were specified as shown in Table 2 in order to obtain a stroke of 150 mm or more and a crash speed of 50 km/h against the test piece.

3.3. Drop Weight Test Results

Figure 12 shows the load (kN)-stroke (mm) curves for a stroke of up to 150 mm after the drop weight test of hat-shaped test pieces. One curve is for pieces joined by spot welding, and the other curve is for pieces joined by MAG-laser hybrid welding at the base area of the vertical wall, which has the greatest energy absorption. The peak load immediately after the weight was dropped and the load for each stroke amount were basically greater with the specimen subjected to continuous MAG-laser welding than with the specimen subjected to spot welding. Figure 13 shows the side and rear surface conditions of the hat-shaped specimen after drop weight testing. Inspection of the images after the weight was dropped shows that the flange side surface of the specimen subjected to spot welding had formed openings and had bent in complex ways, while the specimen subjected to continuous MAG-laser welding had not formed openings and had bent evenly and regularly. No ruptures were found in either the spot-welded joint or the MAG-laser hybrid-welded joint, and the condition of both welds was good.

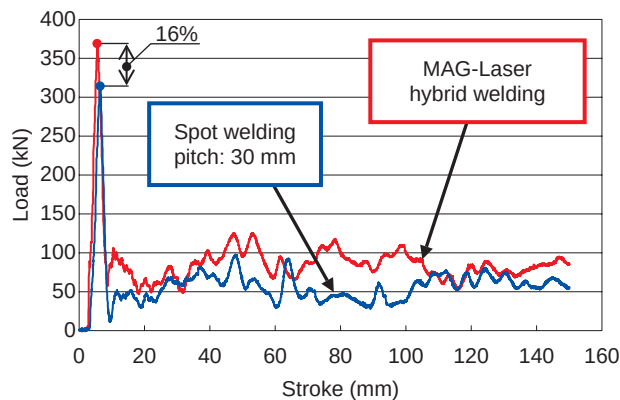


Fig. 12 Comparison of load-stroke curve in axial collapse column between spot welding and MAG-Laser hybrid welding

3.4. Examination of Drop Weight Test Results

The drop weight testing described here showed an increase in energy absorption, and the causes of this increase were examined. The spot welding test piece had openings along the flange portion between the welded spots, and it is very likely that these openings reduced the collapse load.

This is explained by the von Karman effective width theory. Karman's effective width theory is expressed in Eq. (2):

$$P_{cr} = b_e \cdot t \cdot \sigma_r \quad (2)$$

$$b_e = (\pi^2 E k / (12(1-\nu^2)\sigma_r))^{1/2} \quad (3)$$

When $b_e > b$, then:

$$P_{cr} = b \cdot t \cdot \sigma_r \quad (4)$$

P_{cr} is the maximum compressive load; b_e is the effective width; t is the sheet thickness; σ_r is the yield stress; b is the plate width; E is the modulus of longitudinal elasticity; ν is the Poisson ratio; and k is the constant determined by boundary constraint conditions.

When there are angular edges at both ends, $k = 4.00$. When one end has angular edges and the other end is spot welded, $k = 3.15$. When both ends are spot welded, $k = 2.40$. When one end has angular edges and the other end is free, $k = 0.61$. This indicates that the performance of continuous welding results in an increase in the constraint force of the angular edges, which is a boundary constraint condition, so that the collapse load increases⁽⁸⁾. Assuming that the MAG-laser hybrid welded joint is an angular edge and applying that to this hat-shaped test piece, then the maximum collapse load for a MAG-laser hybrid weld can be predicted to rise by 16% relative to a spot weld. The result of the actual drop weight test shows a 16% increase in the maximum collapse load, which correlates closely with Karman's effective width theory. However, comparison with the maximum load from the second wave and thereafter shows an increase of 28.7%, and an

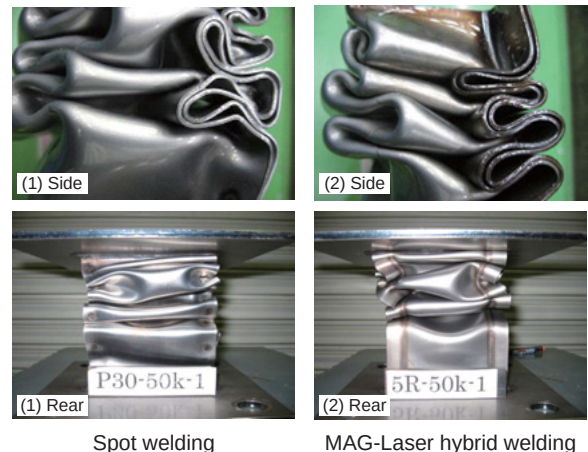


Fig. 13 Appearance of column after collapse test

increase in the average load of 46.6%. This exceeds the efficiency under Karman's effective width theory. This is the range that most of the energy absorption depends on. The formation of openings in this interval in hat-shaped test pieces that have been spot welded accounts for the load difference with MAG-laser hybrid welding, and this difference is thought to have manifested as the difference in overall energy absorption.

Figure 14 shows a comparison of the energy absorption. When the energy absorption with spot welding with welds at the conventional pitch of 30 mm is 100%, then the energy absorption obtained with continuous joining by MAG-laser hybrid welding at the termination of the curve was increased by 38.5% (2.6 times greater than the gain of about 15%⁽¹⁾ obtained through continuous welding by laser only) relative to the spot welding. The use of continuous joining to constrain the angular edge of the flange portion, which contributes the most to energy absorption in the hat-shaped specimen, enables a higher level of energy absorption that could not be obtained using conventional welding methods.

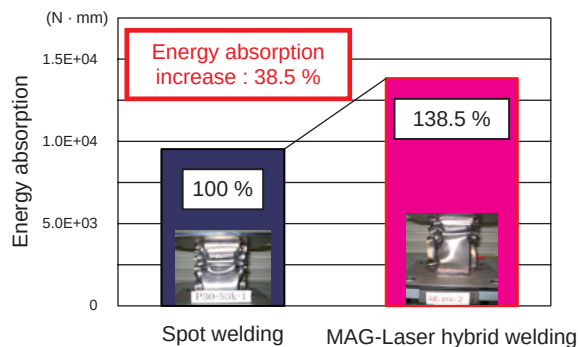


Fig. 14 Comparison of energy absorption between spot welding and MAG-Laser hybrid welding

4. Conclusion

MAG-laser hybrid welding technology and methods for application of that technology were developed with a view towards use on the side frames, which are members that absorb energy during collisions. As a result, the following performance enhancements were achieved:

- (1) MAG-laser hybrid welding technology and applications for that technology were developed to make effective use of gap weldability, which is a characteristic of MAG welding, and of penetrability, which is a characteristic of laser welding. This development enabled continuous welding at the termination of the curve, where energy absorption is highest, and where conventional welding could not be used.
- (2) By enabling continuous welding at the termination of the curve, which laser welding alone had not been capable of joining, the absorption of axial collapse column energy

during collisions was increased a maximum of 38.5% (2.6 times greater than continuous welding by laser only) compared to spot welding.

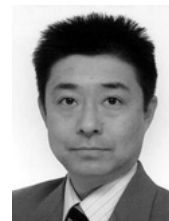
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■ Author ■



Shigeru KOBAYASHI



Tetsuya GOMI